Changes in Soil Physical Characteristics During Transition from Intensive Tillage to Direct Seeding

D. E. Wilkins, M. C. Siemens, S. L. Albrecht

Abstract. *Converting from intensive tillage to no–till systems often increases soil strength, but the long–term impact of no–till on soil strength is not fully understood. Soil strength (evaluated with a hand–held cone penetrometer) and soil water content were evaluated in the top 30 cm of a replicated wheat/fallow rotation in a Pacific Northwest silt loam (coarse–silty, mixed, mesic, typic Haploxeroll). Soil water content was significantly lower in the no–till plots than in intensive tillage plots, which required a correction to remove the impact of soil water on penetrometer resistance. A regression equation was developed to adjust cone index values for soil water content. Comparisons of cone penetration resistance, adjusted for soil water, were made among intensive tillage, first–year no–till, and 17–year no–till. First–year no–till soil was resistant to penetration, but after 17 years of no–till the soil strength was lower and approached tilled conditions. Cone index values just below the plow layer (18 cm) increased from 2 to 3 fold the first year of no–till, but after 17 years of no–till the cone index values were not statistically different between no–till and intensive tillage below the tillage layer. This research demonstrated that silt loam soil structure improved with time during transition from intensive tillage to no–till.*

Keywords. *Soil strength, Penetrometer, No–till, Conservation tillage, Wheat, Cone index, Long–term experiment.*

Over 2.5 million ha of winter wheat (*Triticum aestivum* L.) is dryland farmed in the Columbia Plateau of the Pacific Northwest U.S. in a wheat/fallow cropping system. In the region, summers are hot and dry, and winters are cool and wet. Seventy percent of the total precipitation falls between 1 September and 31 March. Where wheat/fallow is the predominant farming system, mean annual precipitation is less than 450 mm.

This cropping system has been widely used because precipitation for each crop is stored over a two–year period to reduce the risk of crop loss from drought. Although the winter wheat/fallow rotation has been successful, it has degraded soil quality through loss of soil organic matter and erosion. Organic matter has declined in the silt loam soils of the region to less than one–half the level that existed when these prairies were first tilled with moldboard plows late in the nineteenth century (Rasmussen and Smiley, 1997). Results from long–term experiments at Pendleton, Oregon, some started as early as 1931, indicate that loss of soil organic matter content can be stopped by changing the tillage system (Rasmussen and Albrecht, 1997; Wilkins et al., 1998).

Soil erosion is a critical problem because average annual soil losses range from 5 to 50 t/ha in this region (Zuzel et al., 1982) with 80% of erosion occurring during the winter months. Fields are vulnerable to erosion during winter when the soil is frozen, wheat plants are small, and there is very little crop residue on the soil surface.

The conventional Columbia Plateau wheat/fallow production system consists of primary tillage with a moldboard plow, sweep, or chisel plow. Secondary tillage is started with a field cultivator and followed by two to four rodweedings during the summer. The object of this system is weed control and to form a 5– to 7–cm dry–dust mulch for reduced water loss from the deeper soil profile during the hot, dry summer months. Prior to seeding winter wheat in September or October and sometimes as early as June, fertilizer is shank injected into the tilled soil. This system maintains soil water in the profile throughout the summer (Hammel et al., 1981), and seed can be placed into moist soil using deep–furrow grain drills, providing ideal conditions for germination and emergence of winter wheat (Wilkins et al., 1983).

Although this system is effective for raising wheat, it has a negative effect on soil quality. Burying the crop residue over 10 cm deep by moldboard plowing and incorporating it into the top 10 cm of soil with a sweep or chisel plow places the residue in a warm, moist environment ideal for biological decomposition. The warm, moist tilled–soil layer promotes oxidation of the organic matter and loss of CO_2, a greenhouse gas, to the atmosphere (Albrecht et al., 1996).

One option for reducing soil erosion and loss of valuable soil organic matter is to use a no–till system. Soil organic matter is conserved with no–till because oxidation of organic matter is reduced (Albrecht et al., 1996), and surface crop residue reduces soil erosion (Zuzel et al., 1993).

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Converting from intensive tillage to no–till has impacted soil strength and soil water content. Soil strength increases when no–till replaces intensive tillage in medium– to fine–textured soils, as characterized by soil penetration resistance (Hill, 1990; Hammel, 1989; Voorhees and Lindstrom, 1983; Larney and Kladivko, 1989). No–till systems also have a negative influence on seedzone soil water content, a critical factor for October winter wheat seeding in the Columbia Plateau. Hammel et al. (1981) found that soil water content was significantly lower in first year no–till/fallow than in conventional intensive tillage/fallow in a Walla Walla silt loam (coarse–silty, mixed, mesic, typic Haploxeroll). However, studies were conducted over short–term transition from intensive tillage to no–till.

Our objective was to quantify the changes in soil strength (cone index) and soil water content in a typical Columbia Plateau silt loam soil during short– and long–term transition from intensive tillage to a no–till conservation tillage system.

Methods and Materials

A no–till wheat experiment, with four replications, was established in 1981 near Pendleton, Oregon (45° 43' N, 118° 37' W). The site of this experiment is 450 m above sea level. The soil is a well–drained loess (Walla Walla silt loam) 1 to 1.5 m deep over basalt. Topography is nearly level, and annual precipitation is 415 mm. Mean annual temperature is 10.2° C, and the mean monthly temperature ranges from 0° C in January to 20° C in July. The initial crop rotation was winter wheat/spring wheat; changed in 1988 to winter wheat/fallow. The original experimental treatments consisted of five nitrogen rates and residue burn vs. no–burn. In 1989, the burn variable was converted to date–of–seeding. The only tillage in these plots since inception in 1981 was the soil disturbance associated with drill opener at seeding. A Noble model DK–5grain drill with John Deere model HZ drill openers, modified (Wilkins et al., 1983) to place fertilizer below seed and spaced 25 cm apart, has been used since initiation of this experiment in 1981.

In 1996, alternate companion plots (each 2.4 m wide and 30 m long), with four replications, were established adjacent to the original experiment to study changes in soil conditions during transition from intensive tillage/fallow to no–till/fallow. The new plots have conventional intensive tillage and no–till treatments. Each tillage treatment has four plots in fallow and four plots in crop each year. Conventional tillage consisted of moldboard plowing wheat stubble 18 cm deep in April, secondary tillage, 2 to 4 rodweedings, and seeding winter wheat in mid–October. The new no–till plots were fallowed in the non–crop year and seeded with the same Noble DK–5 drill that had been used in the original experiment. Weed control was changed from mechanical rodweeding to chemical control. These additional plots allowed comparisons of soil conditions among conventional tillage, first–year no–till/fallow, and 17–year no–till/fallow.

On 17 October 1997, three soil cores (2 cm diameter) were taken in each plot, sectioned and composited for depth increments of 0–5, 5–10, 10–15, 15–20, and 20–30 cm, and then oven dried at 105° C for 24 hours to determine dry–basis gravimetric soil water content. Cone index measurements were taken the same day with a hand–held recording penetrometer to evaluate changes in soil strength as outlined by ASAE (*ASAE Standards*, 1989). The penetrometer had a 30° cone with base diameter of 12.4 mm. Fifteen cone index readings were automatically recorded (one every 3.5 cm) as the cone was forced into the soil profile. Ten penetration profiles were measured in each plot.

Similar soil water and cone penetrometer measurements were taken in the alternate companion plots in April 1998 after spring tillage, and in August 1998 during the fallow period. These measurements were used to develop a relationship between soil water content and cone index.

Results and Discussion

Soil water content profiles in the fallow plots for the three tillage systems on 17 October 1997 are shown in figure 1. The conventional tillage system maintained more water in the top 25 cm than either the first–year or the 17–year no–till systems. This is consistent with Hammel et al. (1981), indicating that the seedzone soil water profile is drier in no–till/fallow plots than in conventional tillage plots. The long–term no–till plots tended to have more soil water in the top 25 cm than first–year no–till, but those differences were significantly different ($P \leq 0.05$ level) only at the 20 to 30 cm depth.

Soil water content should be 14% (–1 MPa soil water tension for a Walla Walla silt loam) or greater for germination and emergence of winter wheat (Papendick and Campbell, 1981; Wuest et al., 1999). To be sure adequate water is available throughout emergence, seed needs to be placed 2 to 3 cm deep into soil with a 14% soil water content. In this experiment, seed could be placed 7 cm deep in the conventional system for adequate soil water. However, in the first–year no–till system, seed placement of over 10 cm deep would be required for sufficient soil moisture for germination. Placing fertilizer near the seed in dry soil is a potential stress on germination and emergence (Klepper et al., 1983). The no–till/fallow systems would be at a distinct disadvantage for stand establishment because of low soil water content in the seedzone.

Figure 2 presents the results of the cone penetrometer measurements at seeding time in the fallow plots. Soil strength in no–till plots one year after transition is high, and strength decreased after prolonged no–till cropping. After 17 years of no–till, the no–till system builds structure, and the

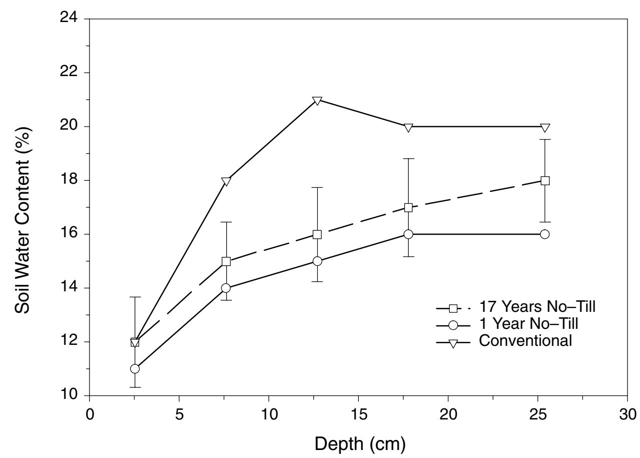

Figure 1. Effect of tillage system on soil water content at seeding.

soil strength approaches that for conventional management associated with tillage. Other studies have shown soil strength increased in no–till systems compared to intensive tillage for short–term and long–term experiments (Hill, 1990; Hammel, 1989; Voorhees and Lindstrom, 1983; Larney and Kladivko, 1989). These results show that, for Walla Walla silt loams, soil strength decreases with time in no–till systems.

Since water content affects cone index (Perumpral, 1987) and each tillage treatment had different soil water content at the time penetrometer measurements were taken, cone index values were adjusted for soil water content using the following process. Regression equations from soil water content versus depth data for each tillage treatment were used to predict soil water content at each depth where a penetrometer reading was taken. In all cases, the predicted water contents were within ±0. 74 g Kg^{-1} of the actual values, and the R^2 values for the regression curves were higher than 0.96. Three–dimensional plots of cone index values versus depth and predicted water content were then made for each tillage treatment using data from a sampling date when soil was wet (April) to a date when soil was very dry (August). A regression surface for each tillage treatment was generated for each plot.

It was found that polynomial equations of the following form gave the best combination of curve shape and high R^2 values (0.83, 0.84, and 0.61) for the one–year no–till, 17–year no–till, and conventional tillage treatments, respectively:

$$CI = a + (b \times MC) + \left(c \times MC^2\right) + \left(d \times MC^3\right) + (e \times Depth) + \left(f \times Depth^2\right) \tag{1}$$

where

CI = cone index (kPa)

MC = gravimetric soil water content (percent dry basis)

$Depth$ = soil depth (cm).

The lower R^2 for the conventional tillage was due to the discontinuity between the dry–loose soil mulch created by rodweeding. An example of a predicted surface and the actual data points is shown for the 17–year no–till data in figure 3. The equations were used to obtain two predicted cone index values at each penetrometer sample depth for each tillage treatment: one based on the actual soil water content for the tillage treatment in question, and the second based on the average soil water content of the three tillage treatments. The actual cone index was multiplied by a constant k (the ratio of the two predicted cone indexes) to obtain an adjusted cone index value. For clarity, in equation form these are represented as:

$$k = \frac{CI_{meanMC}}{CI_{actMC}} \tag{2}$$

$$CI_{adj} = k \times CI_{act} \tag{3}$$

where

k = ratio of the predicted cone index based on the mean soil water content of the three tillage treatments and the predicted cone index based on actual soil water content

$CI_{mean\ MC}$ = predicted cone index based on the mean soil water content of the three tillage treatments

$CI_{act\ MC}$ = predicted cone index based on actual soil water content

CI_{adj} = adjusted cone index.

This cone index adjustment for soil water is similar to the adjustment proposed by Perumpral for silt loam soils (Perumpral, 1987). Depth was included with soil water content as a variable for predicting cone index (CI) because of the nature of the soil and tillage systems. In the conventional intensive tillage system, the top 5 to 10 cm is usually dry–loose soil mulch. From about 15 to 30 cm there is a hard layer (not necessarily dense) caused by silica accumulation associated with nitrogen fertilizer applied to the tillage layer (Baham and Al–Ismaily, 1996). There also tends to be a plow pan developed at 20 to 25 cm where the soil is hard and dense.

Ayers and Perumpral (1982) suggested that cone index is affected by moisture and dry bulk density. Bulk density was calculated from the soil water content samples, but bulk density was highly variable and there were no clear relationships between bulk density and cone index for these data. Furthermore, Bezdicek et al. (1998) found no significant differences in surface bulk density between established no–till systems (longer than 10 years) and conventional intensive tillage, suggesting that perhaps bulk density does not influence cone index in Walla Walla silt loam soils.

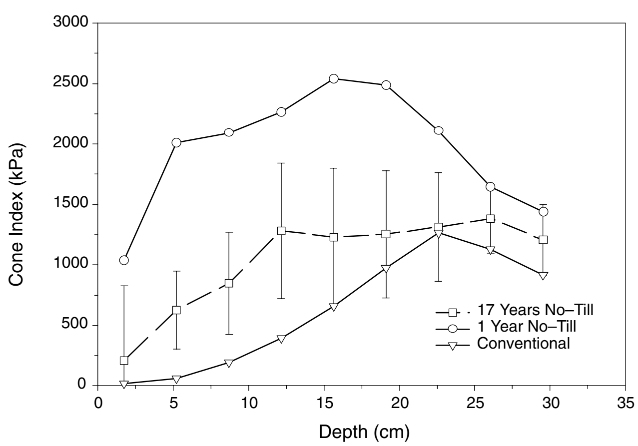

Figure 2. Effect of tillage system on cone index (soil resistance to penetration). The bars indicate ± the least significant difference at P ≤ 0.05 ($LSD_{0.05}$).

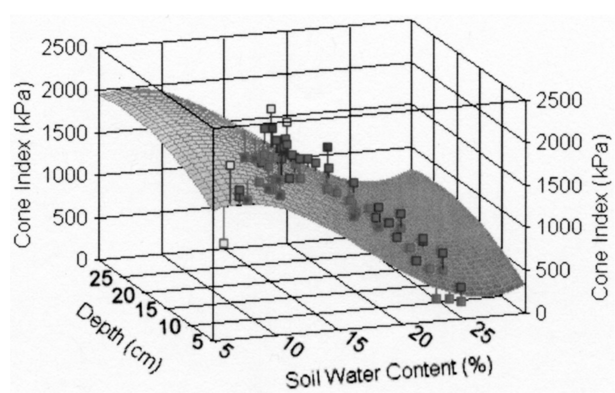

Figure 3. Soil strength as affected by depth and moisture content for 17–year no–till tillage treatment.

Since high water content tends to reduce cone index values, when cone index values were adjusted for soil water content, cone index differences between 17–year no–till and conventional intensive tillage were reduced (fig. 4). The differences were statistically significant ($P \leq 0.05$) at depths of 5 and 9 cm. At all other depths, differences were not significant. This is contrary to other findings for silt loam soils in the Pacific Northwest (Bezdicek et al., 1998) where significant differences were found at 0 to 30 cm. However, the no–till fields reported by Bezdicek et al. (1998) were seeded in the spring when the soils were wet and/or massive no–till drills with disc–type openers were used.

It should be noted that the tillage pan between 15 and 30 cm was beginning to disappear after 17 years of no–till, as suggested by the relatively constant cone index values in this portion of the profile as compared to the conventional or first–year no–till. The top 25 cm of soil in first–year no–till exhibited a significantly ($P \leq 0.05$) higher soil strength (higher cone index) than soil conventionally tilled or no–tilled for 17 years.

Conclusions

There is a significant increase in soil strength as indicated by penetrometer measurements when intensive tillage is replaced with no–till. After 17 years of no–till, the soil strength decreases and approached conditions similar to that created by intensive tillage. Soil water content in the seedzone of the no–till/fallow systems at autumn seeding is still lower than intensive tillage after 17 years of no–till.

It is recommended that where different soil water contents are measured in different tillage treatments, cone index values should be corrected to compensate for soil water content.

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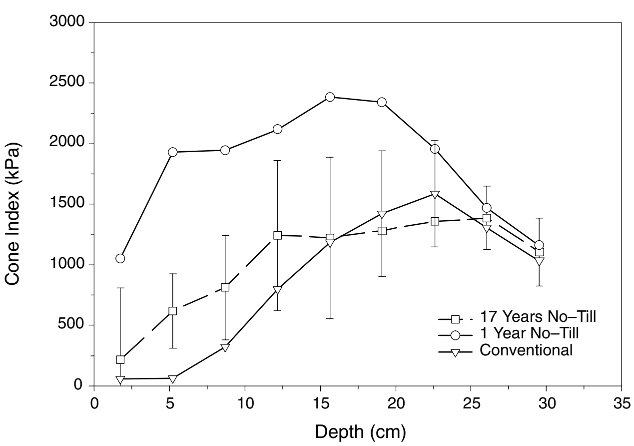

Figure 4. Effect of tillage system on cone index adjusted to mean soil water content. The bars indicate ± the least significant difference at $P \leq 0.05$ ($LSD_{0.05}$).

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